The relationship between muscle and balance performance as a function of age

Denise L Wiksten[*], David H. Perrin[†], Mark L. Hartman[‡], Joe Gieck[§], and Arthur Wellman[**]

Lebsack, D., Perrin, D.H., Hartman, M.L., Gieck, J.H., & Weltman, A. (1996). The relationship between muscle and balance performance as a function of age. Isokinetics and Exercise Science, 6:125-132.

*****Note: Figures may be missing from this format of the document**

Abstract:
Aging is associated with decreases in strength and muscle mass. In addition, the ability to maintain balance decreases with age. Few studies have examined the relationship between isokinetic muscle performance and balance performance. It was the purpose of this study to determine if there is a relationship between muscle and balance performance, and to discover how this relationship is affected by age. Fifty-five healthy females were recruited from two different age groups, 28 females who were 18-30 years of age {mean age = 22.9 years (± 3.4), height = 163.5 cm (±6.5), weight = 64.8 kg (± 15.7)) and 26 females who were > 60 years of age {mean age = 68.1 years (+ 4.8), height = 159.7 cm (± 10.0), weight = 68.0 kg (± 11.4)1. Concentric and eccentric isokinetic muscle performance for the hip, knee, and ankle was measured using the KinCom isokinetic dynamometer. Balance performance was measured using the sharpened Romberg and one-legged stance tests. Younger subjects performed significantly better than older subjects on all muscle and balance performance variables (P = 0.05 to P = 0.0001), except the sharpened Romberg test with the eyes open. The older group exhibited significant relationships between balance and muscle performance measures (r — 0.10 to r — 0.57). In the older group, hip muscle performance was shown to correlate significantly better with balance performance than knee or ankle muscle performance. Also noted was a significantly greater relationship between muscle performance and balance performance with the eyes closed in the older group, as compared to the younger group. This is the first study known to thoroughly examine the relationship between muscle and balance performance. The presence of significant relationships warrants further examination. It is recommended that this relationship be examined in a broad spectrum of young, old, healthy and disabled populations.

1. INTRODUCTION

The ability to maintain an independent lifestyle is of paramount importance for older individuals. Today, more than 50% of those persons 80 years and over are independent in self care [8]. A primary cause of injury and disability in the elderly is the high incidence of falling. The most common type of injury resulting from a fall is a hip fracture, especially in women. Over 90% of hip fractures in persons over 70, are the result of a fall [34]. Falling is a major cause of mortality, morbidity, immobility, and premature nursing home placement [28]. It has been suggested that both muscle strength and balance may be related to the risk of falling in older individuals. Tinetti

---

[*] Sports Medicine/ Athletic Training, University of Virginia, Charlottesville, Virginia, USA
[†] Sports Medicine/ Athletic Training, University of Virginia, Charlottesville, Virginia, USA
[‡] Department of Internal Medicine, University of Virginia, Charlottesville, Virginia, USA
[§] Sports Medicine/ Athletic Training, University of Virginia, Charlottesville, Virginia, USA
[**] Exercise Physiology, University of Virginia, Charlottesville, Virginia, USA

et al. [33] examined multiple risk factors that lead to falls in elderly people. They reported that impaired balance was among the greatest predictors of fall occurrence in community dwelling elders.

Numerous studies have reported that balance decreases with age [2,4,5,25,27,30,31,40,41]. It is also well documented that muscular strength decreases with age [1,3,15,19,22-24,29,37,39]. However, few studies have examined the relationship between muscule and balance performance. Most of the research published on the relationship between muscle and balance performance is centered around elderly persons with a history of falling vs. elderly persons with-out a history of falling. Specific muscular weakness of the lower extremity has been documented in Idlers' as compared to 'non-fallers' [13,20,26,28,39,40]. A recent study reported that measures of lower extremity function (standing balance, walking speed, rise time from a chair) were highly predictive of subsequent disability in mobility and activities of daily living [14]. Brown et al. [6] examined the relationship between strength and function as measured by walking speed, rising from an 18", 16", and 14" chair, and completing an obstacle course in healthy older adults (mean age 80.9 years). The authors reported weak, non-significant relationships for all variables examined except for the relationship between combined hip extension, knee extension, ankle plantar flexion strength and the 14" chair rise.

It is not known, however, whether individual measures of lower extremity strength are related to the ability to maintain balance under a variety of conditions, and it is specifically not known how this relationship is affected by age. Therefore, the purpose of this study was to examine the relationship between isokinetic muscle performance and balance performance as a -function of age in healthy, non-disabled women.

2. METHODOLOGY

2.1. ***Subjects***

Subjects were recruited from two different age groups of healthy, non-disabled women; 18-30 years of age and greater than 60 years of age. A total of 55 women were recruited, of which 28 were young participants (mean age = 22.9 years. (± 3.4), height = 163.5 cm (± 6.5), weight = 64.8 kg (± 15.7), body mass index = 24.2 kg/m² (+ 4.9)) and 27 older participants (mean age = 68.1 years. (+ 4.8), height = 159.7 cm (±10.0), 10.0), weight = 68.0 kg (± 11.4), body mass index = 26.8 kg/m² (+ 4.5)). Subjects who were 60 years or older were given medical clearance by a physician in order to exclude conditions that might put them at risk for cardiovascular complications, or that might hinder balance or muscle performance. These conditions included vestibular dysfunction, postural hypotension, poorly controlled hypertension, uncontrolled angina pectoris, aortic stenosis, peripheral vascular disease, recent myocardial infarction or stroke episodes, or muscle or ligament injuries or dysfunction. All subjects completed a medical history questionnaire that aided in screening those individuals with lower extremity injury or dysfunction, or any other existing conditions that would put them at risk for testing. Subjects were not taking any drugs that might have hindered balance or strength performance, such as antihistamines, coumadin, benzodiazepines (or other sedatives), narcotics, or antihypertensive medications associated with orthostatic hypotension.

Once the subjects provided informed consent to participate in the study, they were asked to refrain from taking medications that might interfere with balance and muscle performance at the time of testing. In addition, the subjects were asked to refrain from any intense physical activity for at least 3 days prior to testing.

3. PROCEDURE

Balance testing was performed before strength testing in order to avoid any fatigue that may occur with strength testing. Balance was tested using the sharpened Romberg (SR) and one-legged stance tests (OLST). The SR test is a modification of the original Romberg test, in which subjects stand in a tandem position with the heel of the front foot directly in front of the toe of the back foot. These tests are well documented in the literature and are proven to have good to excellent inter-tester and test re-test reliability and validity [5,24,32].

After completion of the balance tasks, subjects were allowed to warm-up on a stationary bike for 5 minutes and then perform simple lower extremity stretches for the hip, knee, and ankle musculature. Isokinetic muscle testing for the dominant hip, knee, and ankle joints were performed. Leg dominance was determined as the foot the subject would use to kick a ball or stamp out a fire. The reliability and validity of isokinetic lower extremity muscle performance has also been well documented in the literature [7,10,12,17,18,35,38].

4. INSTRUMENTATION

4.1. ***Balance assessment***

During the balance testing, subjects were surrounded by a three-sided guard rail and wore a harness to protect against falling. Subjects were tested in their bare feet for all balance tests. The shoes and socks were removed to standardize test conditions across subjects (i.e. avoid variations in shoe type and sole surface). The SR was performed with the subjects standing on a level surface with the non-dominant foot placed directly in front of the dominant foot in a straight line. The test was performed with the eyes open and then closed. The subjects were asked to start with their arms at their side and eyes fixed upon an X marked at eye-level on the wall for the eyes-open

trials. Timing began when the subject was ready and continued until the subject lost their foot positioning, grabbed onto any part of the three-sided railing, or opened their eyes on the eyes-closed trial. A maximum time limit of 60 s was set. Three trials were performed with a 1 minute rest interval between each trial for both the eyes open and eyes closed tests. All six trials were recorded, but the best trial for each of the eyes open and eyes closed tests was used for data analysis.

The OLST was performed on both the dominant and non-dominant leg, and with the eyes open and closed. The OLST was performed on a level surface and timing began when the subject was ready. They were instructed to stand on either foot with the other foot suspended off the ground and not touching the supporting leg. The subject's eyes were fixed on an X marked on the wall in front of them during the eyes open trial. Timing was stopped when the subject moved the supporting foot, touched the suspended foot to the ground, used the suspended foot to support the weight-bearing limb, or opened their eyes on the eyes-closed trials. A maximum time limit of 45 s was set. Three trials were performed with a 1 minute rest interval between each trial for both the dominant and non-dominant leg, each with the eyes open and closed. All 12 trials were recorded but the best time for both the dominant and non-dominant leg, each with the eyes open and closed was recorded for data analysis.

4.2. *Assessment of muscle performance*

Measurements of average torque production were obtained using the KinCom Isokinetic Dynamometer (Chattanooga Group Inc., Hixson, TN). Subjects performed flexion and extension movements of their dominant hip, knee, and ankle joints against a lever arm that provided an internal resistance, which accommodated to the muscular force applied. A constant pre-load of 30 N was set for all joints, in order to avoid torque artifact and to prevent the limb from having to catch-up to the accelerating lever arm. Subjects performed two sub-maximal and one maximal warm-up contraction for each joint. A 1 minute rest followed, during which time the subjects were instructed to resist the lever arm as maximally as they could, within their own limits. They were instructed not to hold onto the table and to wait for the examiner's instruction to 'Go'. A total of three sets of intermittent maximal contractions were performed starting with a concentric contraction followed by a 30 s rest period, and then followed by an eccentric contraction. The three interrupted maximal contractions were averaged to give a mean torque curve (N-m) and were presented in the system software. Torque was measured as the force applied by the extremity to the lever arm multiplied by the length of the lever arm as it rotated around the axis of the dynamometer. Average torque was recorded for each joint motion and type of contraction.

4.21. *Hip flexion / extension*

The angular velocity for hip flexion and extension was set at 20°/s. Subjects were tested in a supine position and the axis of the dynamometer was aligned with the greater trochanter of their dominant leg. Their opposite hip was flexed to a 45° angle and their opposite foot was placed on the table. A strap secured the torso against the table, and a strap around the distal thigh held the lever-arm pad in place against the quadriceps or hamstring muscles. The dominant leg was positioned such that the knee was flexed and the ankle was relaxed in a neutral position. Gravity correction procedures were performed prior to data collection. Gravity correction for hip flexion was performed with the hip positioned at 0° of flexion, and for hip extension gravity was corrected with the hip flexed at 50°. The range of motion limits were set at 0 and 50°.

4.2.2. *Knee flexion / extension*

The angular velocity for knee flexion and extension was set at 60°/s. The subjects were tested in a seated position with their hip flexed to 90° and the axis of the dynamometer aligned with the lateral joint line of their dominant knee, just above the head of the fibula. Straps were placed around the chest and hips in order to secure the upper body. A strap around the lower leg was placed two finger widths above the malleoli in order to hold the lever-arm pad in place on the tibia. Gravity correction procedures were performed prior to data collection, and range of motion limits were set at 80 and 5°.

4.2.3. *Ankle dorsiflexion / plantar flexion*

The angular velocity for ankle dorsiflexion and plantar flexion was set at 30°/s. The subjects were tested in a prone position with their knee joint at a 0° angle and the axis of the dynamometer aligned with the lateral malleoli of their dominant leg. A strap was placed around the thighs, and straps from the ankle attachment secured the foot and ankle. Range of motion limits were set at 30 and —10°.

5. DATA ANALYSIS

Analysis of variance was applied to examine the individual variable differences between the young and old groups for both muscle and balance performance measures. The relationships between muscle and balance performance measures were calculated initially using a Multivariate Analysis of Variance (MANOVA) in order to identify significant canonical correlations between the linear combination of muscle performance variables and the linear combination of balance performance variables. Due to the number of variables being examined, this procedure was performed overall using all subjects, in order to identify overall significance. The canonical correlation between balance performance variables and each of the hip, knee, and ankle muscle performance variables were examined separately. Where there were significant canonical correlation's overall, Pearson's Product Moment Correlation Coefficients were examined individually.

In order to examine the muscle and balance relationship differences between the two age groups, Fisher's Z transformations were performed on the r values in both the young and old groups and the z scores were used in a one-way ANOVA. In addition, the z scores for the relationship between balance performance and each muscle group performance for both the young and old groups were used in a one-way ANOVA in order to examine whether hip muscle performance, knee muscle performance, or ankle muscle performance correlated better with balance performance. If significant differences were present, a Tukey-Kramer post hoc analysis was performed to identify the differences.

6. RESULTS

Balance performance data are presented in Table 1. ANOVA revealed significant differences ($P < 0.0001$) between the young and old groups for all balance performance measures with the exception of the SR test with the eyes open (P 0.15).

Table 2 shows muscle performance values obtained from the KinCom analysis, Significant differences (P

Table 1
Comparison of balance performance variables in young and, old subjects (seconds)

Test	Young	Old
SREO	60.00 (0)	56.63 (12.25)
SREC	58.49 (8.02)	25.14 (23.68)[a]
OLDEO	45.00 (0)	33.05 (14.41)[a]
OLDEC	31.34 (15.35)	5.28 (2.70)[a]
OLNEO	45.00 (0)	33.27 (15.98)[a]
OLNEC	27.94 (17.05)	5.52 (5.03)[a]

'Significantly different than the young group *(P* < 0.0001) SREEO' Sharpened Romberg, eyes open; SREC, Sharpened Romberg, eyes closed; OLDEO, One-legged stance test, dominant leg, eyes open; OLDEC, One-legged stance test, dominant leg, eyes closed; OLNEO, One-legged stance test, non-dominant leg, eyes open; and OLNEC, One-legged stance test, non-dominant leg, eyes closed.

Table 2
Comparison of measures of muscle performance variables in young and old subjects (average torque in *Nm)*

Movement	Young	Old
HFC	233.1 (48.7)	148.4 (35.8)[a]
HFE	259.5 (59.6)	195.6 (53.0)[a]
HEC	207.0 (58.0)	135.7 (47.0)[a]
HEE	273.9 (75.9)	205.3 (59.2)[a]
KFC	151.2 (29.4)	85.9 (19.4)[a]
KFE	181.9 (39.7)	136.5 (28.3)[a]
KEC	289.5 (63.6)	187.7 (41.0)[a]
KEE	314.7 (70.6)	249.1 (51.2)[a]
ADC	110.1 (22.1)	85.8 (13.3)[a]
ADE	162.3 (30.9)	135.1 (27.5)[a]
APC	254.5 (55.1)	145.9 (49.3)[a]
APE	307.4 (65.9)	221.7 (68.2)[a]

'Significantly different than the young group *(P* < 0.001)
HFC, Hip flexion, concentric; KEC, Knee extension, concentric; HFE, Hip flexion, eccentric; KEE, Knee extension, eccentric; HEC, Hip extension, concentric; ADC, Ankle dorsiflexion, concentric; HEE, Hip extension, eccentric; ADE, Ankle dorsiflexion, eccentric; KFC, Knee flexion, concentric; APC, Ankle plantar flexion, concentric; KFE, Knee flexion, eccentric; and APE, Ankle plantar flexion, eccentric.

< 0,001) were observed between the young and old groups on all muscle performance measures.

Overall MANOVA revealed the presence of significant canonical correlation's (rc) between the balance performance variables and hip, knee, and ankle muscle, performance variables (rc = 0,70, P < 0.05; rc = 0.72, P < 0.05; and rc = 0.71, P < 0.05, respectively). Therefore, Pearson's correlation matrices for both the young and old groups were performed.

Pearson's correlation matrices for balance and muscle performance in the older group are presented in Table 3. Although several significant relationships were found between muscle performance and balance performance (r > 0.37, P.< 0.05), none of the correlations were > r = 0.71 (50% common variance).

A similar analysis for the younger group is shown in Table 4. There were no statistically significant relationships between muscle and balance performance in the younger group (r > 0.36, P < 0.05).

Z transformations were performed on the r values in both the young and old groups. The z scores were then used in a one-way ANOVA to identify significant differences between the young and old groups for the relationship between muscle and balance performance. ANOVA revealed a significantly greater relationship between the sharpened Romberg test with the eyes closed and muscle performance in the older group as compared to the younger group. In addition, the older group had a significantly greater relationship between the dominant and non-dominant one-legged stance tests with the eyes closed and muscle performance than the younger group.

Table 3
Correlation matrix for balance performance and muscle performance variables in older subjects

	SREO	SREC	OLDEO	OLDEC	OLNEO	OLNEC
HFC	0.06	0.44[a]	0.39[a]	0.44[a]	0.55[a]	0.46[a]
HFE	−0.02	0.29	0.55[a]	0.53[a]	0.42[a]	0.35
HEC	−0.08	0.40[a]	0.29	0.41[a]	0.39[a]	0.31
HEE	0.11	0.26	0.41[a]	0.57[a]	0.24	0.17
KFC	0.02	0.28	0.13	0.30	0.17	0.29
KFE	−0.07	0.08	−0.04	0.27	−0.02	0.17
KEC	0.14	0.27	0.08	0.18	0.35	0.12
KEE	−0.10	0.16	0.18	0.29	−0.03	0.13
ADC	0.36	0.33	0.03	0.11	0.28	0.44[a]
ADE	0.14	0.02	0.06	0.07	0.18	0.24
APC	0.14	0.34	0.31	0.40[a]	0.19	0.20
APE	−0.04	0.12	0.39[a]	0.40[a]	0.15	0.002

[a] Significant r value at $P < 0.05$ (critical r = 0.37).
HFC, Hip flexion, concentric; KEC, Knee extension, concentric; HFE, Hip flexion, eccentric; KEE, Knee extension, eccentric; HEC, Hip extension, concentric; ADC, Ankle dorsiflexion, concentric; HEE, Hip extension, eccentric; ADE, Ankle dorsiflexion, eccentric; KFC, Knee flexion, concentric; APC, Ankle plantar flexion, concentric; KFE, Knee flexion, eccentric; APE, Ankle plantar flexion, eccentric; SREO, Sharpened Romberg, eyes open; SREC, Sharpened Romberg, eyes closed; OLDEO, One-legged stance test, dominant, eyes open; OLDEC, One-legged stance test, dominant, eyes closed; OLNEO, One-legged stance test, non-dominant, eyes open; and OLNEC, One-legged stance test, non-dominant, eyes closed.

Table 4
Correlation matrix for balance performance and muscle performance variables in younger subjects

	SREO	SREC	OLDEO	OLDEC	OLNEO	OLNEC
HFC	—	−0.06	—	−0.13	—	−0.27
HEC	—	−0.34	—	0.13	—	−0.04
HFE	—	0.10	—	−0.08	—	−0.13
HEE	—	0.06	—	0.001	—	−0.02
KFC	—	0.04	—	−0.18	—	−0.25
KFE	—	−0.22	—	0.12	—	0.05
KEC	—	0.05	—	−0.17	—	−0.20
KEE	—	−0.19	—	−0.10	—	−0.15
ADC	—	−0.41	—	0.06	—	0.07
ADE	—	−0.35	—	0.08	—	0.06
APC	—	0.11	—	−0.13	—	0.06
APE	—	−0.31	—	0.08	—	0.16

— No variance between scores, therefore no correlation's were computed
[a] Significant r value at $P < 0.05$ (critical r = 0.36).
HFC, Hip flexion, concentric; KEC, Knee extension, concentric; HFE, Hip flexion, eccentric; KEE, Knee extension, eccentric; HEC, Hip extension, concentric; ADC, Ankle dorsiflexion, concentric; HEE, Hip extension, eccentric; ADE, Ankle dorsiflexion, eccentric; KFC, Knee flexion, concentric; APC, Ankle plantar flexion, concentric; KFE, Knee flexion, eccentric; APE, Ankle plantar flexion, eccentric; SREO, Sharpened Romberg, eyes open; SREC, Sharpened Romberg, eyes closed; OLDEO, One-legged stance test, dominant, eyes open; OLDEC, One-legged stance test, dominant, eyes closed; OLNEO, One-legged stance test, non-dominant, eyes open; and OLNEC, One-legged stance test, non-dominant, eyes closed.

When the relationship between muscle performance and overall balance performance with the eyes open was compared to overall balance performance with the eyes closed, the older subjects exhibited a significantly greater relationship ($P < 0.0003$) between muscle and balance performance with the eyes closed than the younger group.

The z-scores were also computed from the r values for relationship differences among the muscle groups tested and balance performance for both the young and old groups. ANOVA revealed significant ($P < 0.001$) relationship differences between balance per formance and the muscle groups tested in the older subjects. Tukey-Kramer post hoc analysis revealed that hip muscle performance correlated significantly better with balance performance than knee or ankle muscle performance. In the younger group, no significant relationship differences between balance performance and the muscle groups were noted.

7. DISCUSSION

The present findings are consistent with numerous studies which have reported that balance decreases

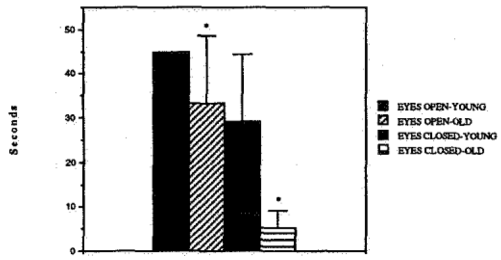

Fig. 1. Age-related decline in balance with the eyes closed as compared to the eyes open *(P* < 0.0001).

with age [2,4,5,25,27,30,31,40,41]. The results of this study also support the well documented finding that strength decreases with age [1,3,15,19,22-24,29,37,39]. The principal findings of our study, however, indicate that the relationship between muscle and balance performance is dependent on age, specific muscle group parameters, and whether balance is performed with the eyes open or closed.

7.1. Balance performance

We found a significant age effect for the sharpened Romberg test with the eyes closed and the one-legged stance tests with the eyes open and closed, which is consistent with the findings of Rikli and Busch [25] who reported a significant age effect for the one-legged stance test with the eyes open. Differences between young and old subjects for the dominant one-legged stance test with the eyes open were smaller than with the eyes closed. A similar trend was seen with the non-dominant one-legged stance test (Fig. 1). These data support the suggestion that as people age, there is a greater decline in balance tasks with the eyes closed, as compared to with the eyes open [24].

7.2. ***Relationship between muscle and balance performance***

Our results indicate that while the relationship between muscle and balance performance in the older group is not strong (r < 0.57), it is dependent on age. In the older group, it appears that muscle performance may have played a role in the subjects' ability to maintain balance (Table 3). This relationship was not seen in the younger population. We hypothesize that the length of testing time required to perform the balance measures (i.e. 45-60 s) may have elicited muscle fatigue, thereby taxing the lower extremity muscles. Fatigue may have affected the older subjects to a greater degree than the younger subjects. Therefore, the potential for a greater relationship between balance and muscle performance measures was possi ble in the older group. The increased potential for muscular fatigue in older persons is supported by the literature documenting age-related declines in strength [19,23,24,29,37]. Fiatrone et al. [11] examined the effects of an 8-week quadricreps isotonic strength training program in older adults (n = 10, mean age 90.2 years). All subjects exhibited significant improvements in quadriceps strength. Five of the 10 subjects completed a tandem gait test, and exhibited a 48% improvement after training.

Results from this study are encouraging, however, the number of subjects tested was small and a control group was not used for comparison.

In the present study, concentric and eccentric isokinetic hip, knee, and ankle muscle performance was assessed and compared to static balance performance with the eyes open and closed. While there were statistically significant correlations between muscle and balance performance in the older group, there was a great deal of unexplained variance. The amount of unexplained variance should be considered when interpreting the clinical relevance of these statistically significant findings. There needs to be more thorough research examining the cause and effect relationship between muscle and balance performance.

The relationship between muscle and balance performance, may also be dependent on the specific muscle group tested. We found a significantly greater relationship between balance performance measures and hip muscle performance than knee or ankle muscle performance in the older subjects. These findings support the report of Robbins et al. [26] who examined hip, knee, and ankle muscular performance in a group of 'falters' and 'non-fallers'. They found significantly greater hip, knee, and ankle muscle weakness in the `falters' as compared to the 'non-fallers'. In addition, the authors reported that hip weakness, among other factors, significantly and independently predicted falling in the subjects studied. Tinetti et al. [34] also reported hip weakness to be the single best predictor of falls in the elderly.

We also found that our older subjects exhibited a significantly greater relationship between balance performance with the eyes closed and muscle performance, than did our younger subjects (Fig. 2). These findings may have clinical application for older individuals in that normal aging may result in visual compromises, such as decreased visual acuity, restricted visual field, and reduced depth perception. This impaired use of visual reference may require that older persons rely more on other adaptive responses, such as proprioceptive adaptations [36]. Based on the results of their study, Maki et al. [21], reported that the importance of proprioceptive, cutaneous, and vestibular inputs increased when visual inputs were

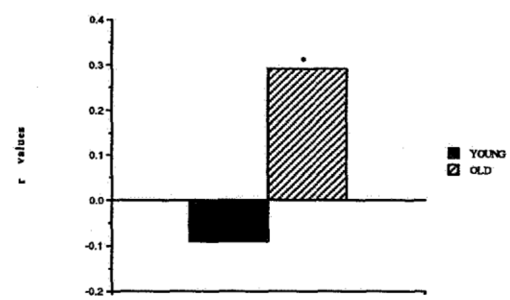

Fig. 2. The relationship between muscle and balance performance with the eyes closed as a function of age *($P < 0.0003$)*.

unavailable. Several reports have examined visual, vestibular, and proprioceptive input for the control of balance across a wide range of circumstances [31,32,36]. The consensus is that during different periods of life and depending on the presence of certain diseases or conditions, the reliance on one or more of these systems varies. Children tend to rely more on proprioceptive and vestibular cues, whereas adults rely more on visual cues, and the elderly tend to control postural stability almost entirely by visual influx [36]. If any one of these systems is impaired for any reason, there will be a greater reliance on the other systems to compensate for the inadequacies [28].

In addition to visual changes that occur physiologically with age, there are also visual compromises that result with darkness. For example, elderly persons who get out of bed in the middle of the night, are at risk for falling as a result of visual compromise caused by the darkness. A recent study by Cummings et al. [9] revealed that poor depth perception and reduced visual contrast sensitivity independently increased the risk of hip fractures. Lord et al. [20] also reported low contrast visual sensitivity to be an important predictor of falling. Hu and Woollacott [16] examined the effects of multi-sensory balance training in older adults and found that static balance performance increased significantly more when balance training was conducted with the eyes closed as opposed to the eyes open on a firm support surface. They concluded that the trained subjects were able to weigh their sensory inputs and select the most reliable sensory information for postural control. Therefore, increased performance of the lower extremity muscles may be even more important for older individuals in maintaining postural control in a variety of situations.

8. CONCLUSIONS AND CLINICAL IMPLICATIONS

The findings of the present study support previous findings that the level of muscle and balance perfor mance is lower in older compared to younger subjects. When isokinetic muscle performance measures are considered, a statistically significant relationship exists between muscle and balance performance in older subjects. The results of the present study are unique in that the relationship reported was between individual muscle and balance performance measurements, as opposed to documenting weakness in 'fallen' vs. `non-fallers', or predicting risk factors of falling in older persons.

The data from the present study suggest that by maintaining muscle performance, balance performance may also be maintained. This is especially important for older individuals because of their increased risk for falling as a result of numerous physiological changes that commonly occur with aging.

Acknowledgements

This study was supported in part by a NIH grant (AG 10997-01) and the General Clinical Research Center at the University of Virginia, NIH RR 00847.

REFERENCES

[1] Aniansson A, Grimby G, Rundgren A. Isometric and isokinetic quadriceps muscle strength in 70-year-old men and women. Scand J Rehab Med 1980;12:161-168.
[2] Aniansson A, Rundgren A, Sperling L. Evaluation of functional capacity in activities of daily living in 70-year-old men and women. Scand J Rehab Med 1980;12:145-154.
[3] Aniansson A, Sperling L, Rundgren A, Lehnberg E. Muscle function in 75-year-old men and women. A longitudinal study. Scand J Rehab Med 1983;9:92-102.
[4] Bohannon RW, Larkin PA, Cook AC, Gear J, Singer J. Decrease in timed balance test scores with aging. Phys Ther 1984;64(7):1067-1070.
[5] Briggs RC, Gossman MR, Birch R, Drews JE, Shaddeau SA. Balance performance among non-institutionalized elderly women. Phys Ther 1989;69(9):748-756.

[6] Brown M, Sinacore DR, Host HH. The relationship of strength to function in the older adult. J Geront 1995;50A: 55-59.
[7] Bumett CN, Betts EF, King WM. Reliability of isokinetic measurements of hip muscle torque in young boys. Phys Ther 1990;70:244-249.
[8] Committee on a National Research Agenda on Aging. Extending Life, Enhancing Life National Academy Press: Washington, DC, 1991.
[9] Cummings SR, Nevitt MC, Browner WS, Stone K, Fox KM, Ensrud KE, Cauley J, Black D, Vogt TM. Risk factors for hip fractures in white women. N Engl J Med 1995;332(12): 767-773.
[10] Feiring DC, Ellenbecker TS, Derscheid GL. Test-retest reliability of the biodex isokinetic dynamometer. J Orthop Sports Phys Ther 1990;11:298-300.
[11] Fiatrone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA, Evans WJ. High-intensity strength training in nonagenarians: effects on skeletal muscle. J Am Med Assoc 1990;263:3029-3034.
[12] Friedlander AL, Block JE, Byl NN, Stubbs HA, Sadowsky HS, Genant HK. Isokinetic limb and trunk muscle performance testing: short term reliability. J Orthop Sports Phys Ther 1991;14:220-224.
[13] Gehlsen GM, Whaley MH. Falls in the elderly: Part II, balance, strength, and flexibility. Arch Phys Med Rehab 1990;71:739-741.
[14] Guralnik JM, Ferrucci L, Simonsick EM, Salive ME, Wallace RB. Lower extremity function in persons over the age of 70 years as a predictor of subsequent disability. N Engl J Med 1995;332:556-561.
[15] Harries UJ, Bassey EJ. Torque-velocity relationships for the knee extensors in women in their 3rd and 7th decades. Eur J Appl Physiol 1990;60:187-190.
[16] Hu MH, Woollacott MH. Multi-sensory training of standing balance in older adults: I. Postural Stability and one-leg stance balance. J Geront 1994;49(2):M52-M61.
[17] Kamofel G, Wilkinson K, Lentell G. Reliability of isokinetic muscle testing at the ankle. J Orthop Sports Phys Ther 1989;11:150-154.
[18] Kues JM, Rothstein JM, Lamb RL. Obtaining reliable measurements of knee extensor torque produced during maximal voluntary contractions: an experimental investigation. Phys Ther 1992;72:492-501.
[19] Larsson L, Grimby G, Karlsson J. Muscle strength and speed of movement in relation to age and muscle morphology. J Appl Physiol 1979;46:451-456.
[20] Lord SR, Ward JA, Williams P, Anstey KJ. Physiological factors associated with falls in older community-dwelling women. J Am Geriatr Soc 1994;42:1110-1117.
[21] Maki BE, Holliday PJ, Topper AK. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. J Geront 1994;49(2): M72-M84.
[22] Murray PM; Duthie EH, Garnbert SR, Sepic SB, Mollinger LA. Age related differences in knee muscle strength in normal women. J Geront 1985;40(3):275-280.
[23] Nakao M, Inoue Y, Murakami H. Aging process of leg muscle endurance in males and females. Eur J Appl Physiol 1989;59:209-214.
[24] Potvin AR, Syndulko K, Tourtellotte WW, Lemmon JA, Potvin JH. Human neurologic function and the aging process. J Am Geriatr Soc 1980;28(1):1-9.
[25] Rikli R, Busch S. Motor performance of women as a function of age and physical activity level. J Geront 1986;41(5):645-649.

[26] Robbins AS, Rubenstein LZ, Josephson KR, Schulman BL, Osterweil D, Fine G. Predictors of falls among elderly people. Arch Intern Med 1989;149:1628-1633.
[27] Rubenstein LZ, Josephson KR, Robbins AS. Falls in the nursing home. Ann Inntern Med 1994;121:442-451.
[28] Rubenstein LZ, Robbins AS, Schulman BL, Rosado J, Osterweil D, Josephson KR. Falls and instability in the elderly. J Am Geriatr Soc 1988;36:266-278.
[29] Serratrice G, Roux I-I, Aquaron R. Proximal muscular weakness in elderly subjects. J Neurol Sci 1968;7:275-299.
[30] Sheldon JH. On the natural history of falls in old age. British Med J 1960;4:5214-1690.
[31] Sheldon JH. The effect of age on the control of sway. Geront Clin 1963;5(3):129-138.
[32] Stones MJ, Kozma A. Balance and age in the sighted and blind. Arch Phys Med Rehab 1987;68:85-89.
[33] Tinetti ME, Baker DI, McAvay F, Claus EB, Garrett P, Gottschalk M, Koch ML, Trainor K, Horwitz RI. A multi-factorial intervention to reduce the risk of falling among elderly people living in the community. N Engl J Med 1994;331:821-827.
[34] Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med 1988;319:1701-1707.
[35] Tredinnick TJ, Duncan PW. Reliability of measurements of concentric and eccentric isokinetic loading. Phys Ther 1988;68:656-659.
[36] Trueblood PR, Rubenstein LZ. Assessment of instability and ,gait in elderly persons. Compreh Ther 1991;17(8):20-29.
[37] Vandervoort AA, McComas AJ. Contractile changes in opposing muscles of the human ankle joint with aging. J Appl Physiol 1986;61:361-367.
[38] Wennerberg D. Reliability of an isokinetic dorsiflexion and plantar flexion apparatus. Am J Sport Med 1991;19:519-522.
[39] Whipple RH, Wolfson LI, Amerman PM. The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. J Am Geriatr Soc 1987;35(0:13-20.
[40] Wolfson LI, Whipple R, Amerman P, Kleinberg A. Stressing the postural response, a quantitative method for testing balance. J Am Geriatr Soc 1986;34:845-850.
[41] Woollacott MH, Shumway-Cook A, Nashner LM. Aging and posture control: changes in sensory organization and muscular coordination. Int J Aging Human Dev 1986;23(4:97-114.